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On the Performance of a Multi Story Irregular Apartment Building Model Under Seismic Load in Indonesian Moderately High Seismicity Region

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Abstract – Purbalingga is regency with a potential moderately high seismicity requiring compliance of planning and implementation rules of the earthquake-resistant structural system. The purpose of this research is to evaluate the performance of a ten-story irregular apartment building model in Purbalingga due to the seismic load. The research is necessarily conducted in order to provide information on impacts and mitigation strategies that should be implemented. This research was conducted based on the seismic load of 2002 and 2012 Indonesian National Standard (SNI) including linear static analysis, dynamic response analysis, and pushover analysis. Based on linear static analysis, it shows that the base shear is reduced and the drift ratio level decreases respectively for X and Y direction. Meanwhile, based on the dynamic response analysis, the drift ratio level also decreases respectively for X and Y direction. In addition, the pushover analysis indicates that the performance of this apartment building model is still at Immediate Occupancy (IO) level as the post-earthquake damage state that remains safe to occupy, essentially retains the pre-earthquake design strength and stiffness of the structure. The risk of lifethreatening injury as a result of structural damage is very low, and although some minor structural repairs may be appropriate, these would generally not be required prior to reoccupancy.

Keywords: Apartment, performance, Purbalingga, seismic load, structure

Introduction

The building has numerous functions for human activities including residential, religious, business, social, cultural, either general or particular activities, no exception in Indonesia. The Article 8 of Law of the Republic of Indonesia No. 28 of 2002 Concerning Buildings, states that each building construction is required to meet the administrative requirements including the status of land rights, building ownership, and building permits. Furthermore, Building Construction Permit (IMB) stipulated in Government Regulation No. 36 of 2005 concerning on Implementation of Regulations of Law No. 28 of 2002, Regulation of the Minister of Public Works No. 24 of 2007 on IMB Technical Guidelines and Regulation of the Minister of Home Affairs No. 32 of 2010 on IMB Guidelines.

The apartment is a building which functions meet the requirements for residential activities. Nowadays, due to the economic and population growth, the needs of apartments are also highly increasing. An apartment building actually needs broader land. In facts, the one provided is very limited. One effort to optimally utilize that small land is by vertically constructing a story building. There are many aspects to consider in designing a story building, such as function, security, convenience, and efficiency or economic factors. Security is the main aspect of constructing a multistory building. The calculation on designs and structures of a multistory building is generally made to maintain the vertical gravitational forces (dead and live loads) as well as the horizontal forces of winds and earthquakes.

Due to the seismicity, Indonesia has made regulatory changes on the earthquake of Indonesian National Standards, SNI 03-1726-2002 to SNI 1726:2012, which may change the building structural behaviors. Based on details of Indonesian earthquake hazard map of 2010 (SNI 1726:2012), Purbalingga regency has a Spectral Acceleration response, SA, (short period, or 0.2 sec) of 0.792 g and Spectral Acceleration, SA, (long-period or 1.0 sec) of 0.323 g as shown in Figure 1.

Figure 1. Spectral Acceleration response, SA, (short period, or 0.2 sec) and Spectral Acceleration, SA, (long-period or 1.0 sec) in Purbalingga regency (SNI 1726:2012)

Based on FEMA P-154 (FEMA, 2015), an area with a Spectral Acceleration response, SA, (short-period, or 0.2 sec) greater than or equal to 0.500g but less than 1.000g, and a Spectral Acceleration response, SA (long-period or 1.0 sec) greater than or equal to 0.200g but less than 0.400g, is categorized into an area with a potential moderately high seismicity. Thus, Purbalingga is a region with a potential moderately high seismicity which requires the compliance of planning rules and structural system implementation of earthquake resistance on each building structure to establish in Purbalingga. In facts, those planning rules/earthquake resistance building structure implementation have not been completely applied. Generally, the high level of the damage and casualties caused by the occurrence of earthquakes, especially in the areas that were directly adjacent to the centers of the epicenter, a high danger zone, indicates that the mitigation efforts by both the government and society were still low (Affan *et al*, 2016). The purpose of this research is to evaluate the performance of a ten-story irregular apartment building model in Purbalingga due to the seismic load. This is necessary to conduct in order to provide information on impacts and mitigation strategies should be applied.

Buildings with irregular structures either horizontally or vertically have higher vulnerability than those with regular ones. An example of building with horizontally irregular structures is that with re-entrant corner irregularity as both projections on structural plans of the re-entrant corner are greater than 15% of structural plan dimension with a specified direction, as shown in Figure 2. An example of building with vertically irregular structures is that with in-plane discontinuity irregularity as there is an offset of the retaining elements which is greater than the width (d) or there exists a reduction in stiffness of the story below as shown in Figure 3.

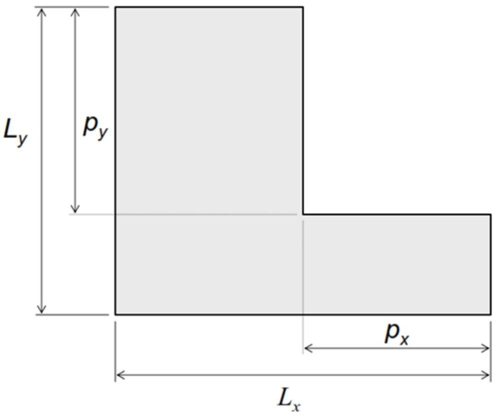


Figure 2. Re-entrant corner irregularity **(**FEMA 451B)

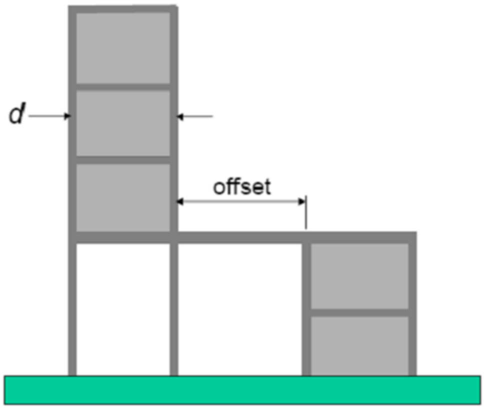


Figure 3. In-plane discontinuity irregularity (FEMA 451B)

Satyarno (2010) states that the level of seismicity is determined by two main factors: the hazard and the vulnerability. Hazard cannot be decreased since it belongs to natural phenomenon. In this way, the level of seismicity can only be decreased by lowering vulnerability. In relation to the study of Earthquake Engineering**,** nowadays there are two important terms; *Performance-based Design* and *Performance-based Evaluation*. Performance-based design is an approach to the design of any complexity of building, from single-detached homes up to and including high-rise apartments and office buildings. A building constructed in this way is required to meet certain measurable or predictable performance requirements, such seismic load, without a specifically prescribed method by which to attain those requirements. *Performance-based evaluation*. is the process of systematically comparing and matching the performance in use of building assets with explicitly documented or implicitly criteria for their expected performance.

Materilas and Methods

Apartment Building Model

The apartment building model is adjusted based on criteria of irregular structures, in this case, the horizontally irregular structures in which the dimensional weight of X and Y axis is different with the soil condition which is in a moderate state. Simplification is performed when designing, such as stiffness level of axis x positive and negative and that of axis y positive and negative are equally made. The accounted dead loads include the structures' self weight consisting of beams, columns, walls, and floor plates profile. Equal loads on beams are to put the wall loads in. Meanwhile, the plate loads are modeled like properties based on plate dimensions. The live loads for apartment building type of 250 kg/m^2 are modeled as equal loads distributed on plates. To determine the structures' self weight, an analysis is conducted based on the concept of equlibrium forces. The structure plan is shown in Figure 4, while the evaluated 3-dimensional apartment building model is shown in Figure 5.

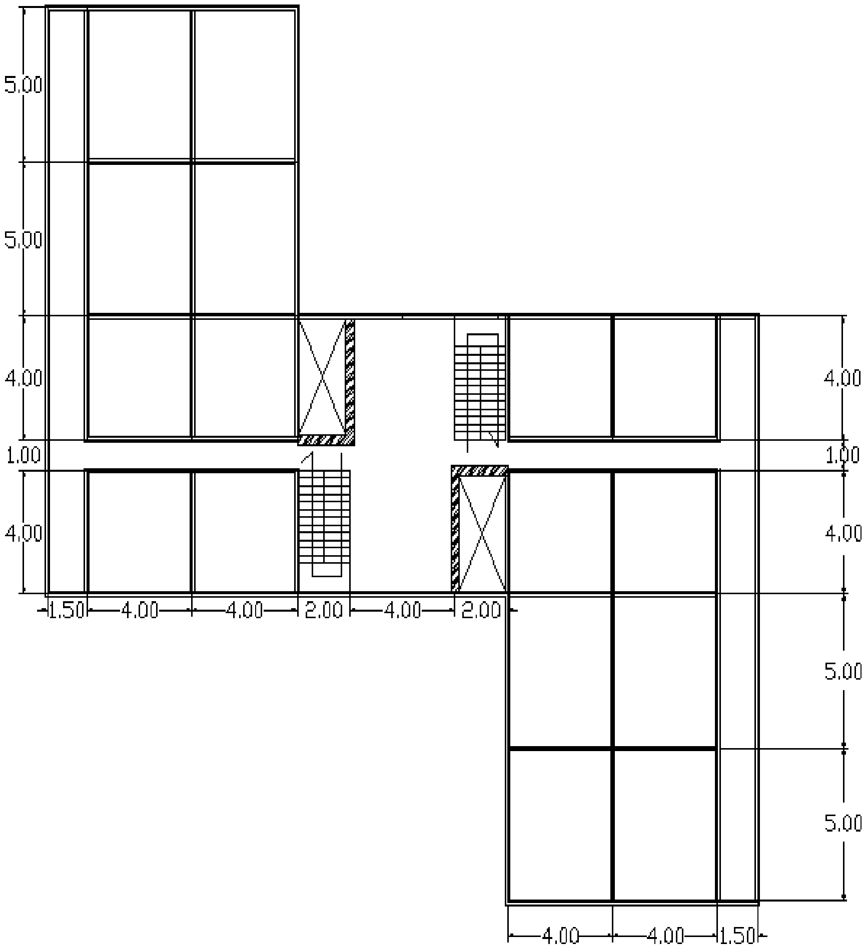


Figure 4. The structure plan

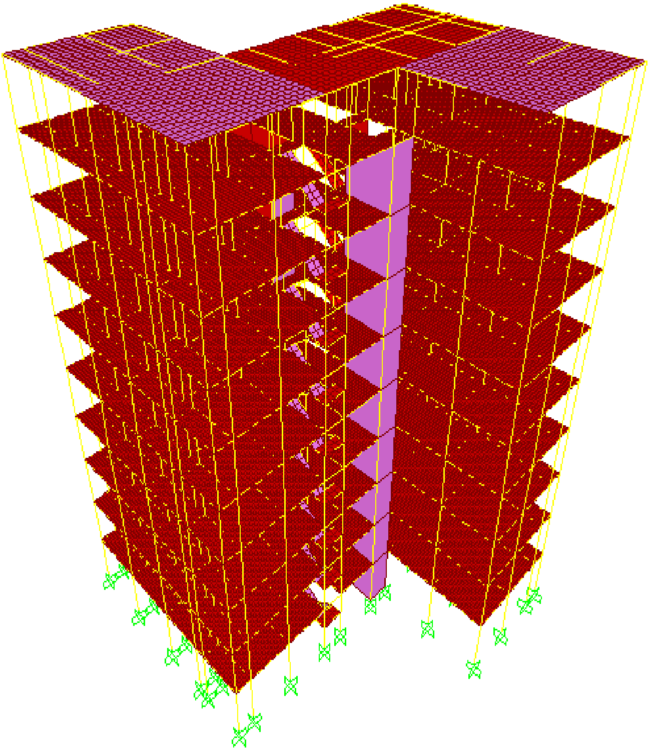


Figure 5. 3-dimensional apartment building model

Structure Details

The columns use a profile I of 600.300.12.17 to floor 1-5 and a profile I of 250.250.11.11 to floor 6-10. Meanwhile, the beam uses profile I of 600.300.12.17 with 64 pieces of shear connectors. Every two shearconnectors is mounted in each floor with a distance of 18.75 cm to floor 1-9. Roof beams use profile I of 500.300.11.15 with 52 pieces of shear connectors. Each two shearing connectors are mounted in each distance of 23.10 cm long. The stair planning results in the *optrede* calculation of 20 cm, 25 cm, and an angle of 38° with the stair step number of 19 units. The stair plan and front view are shown in Figure 6, while the top view is shown in Figure 7.

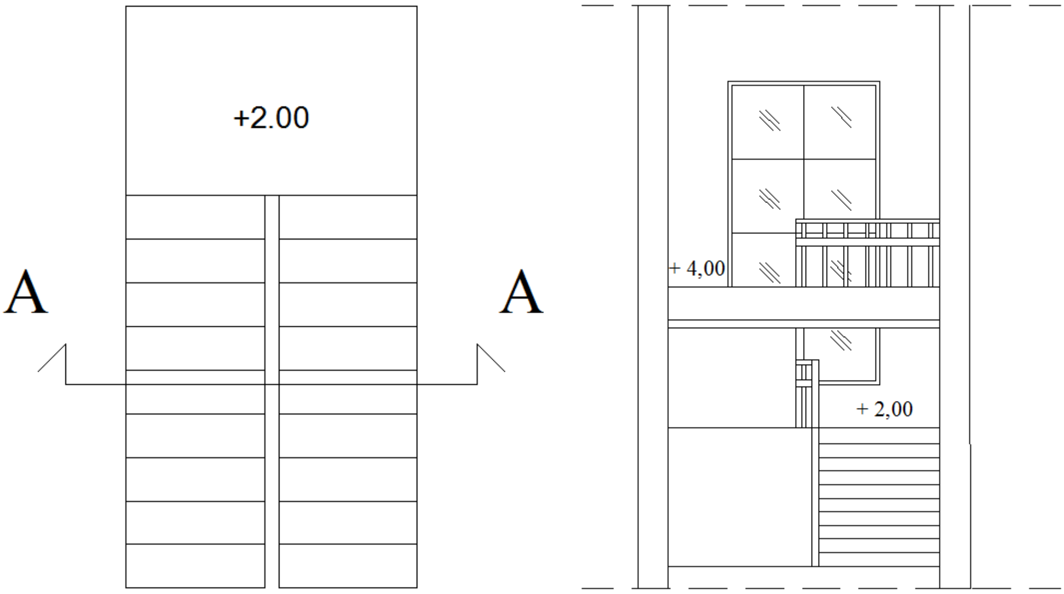


Figure 6. Stair plan and front view

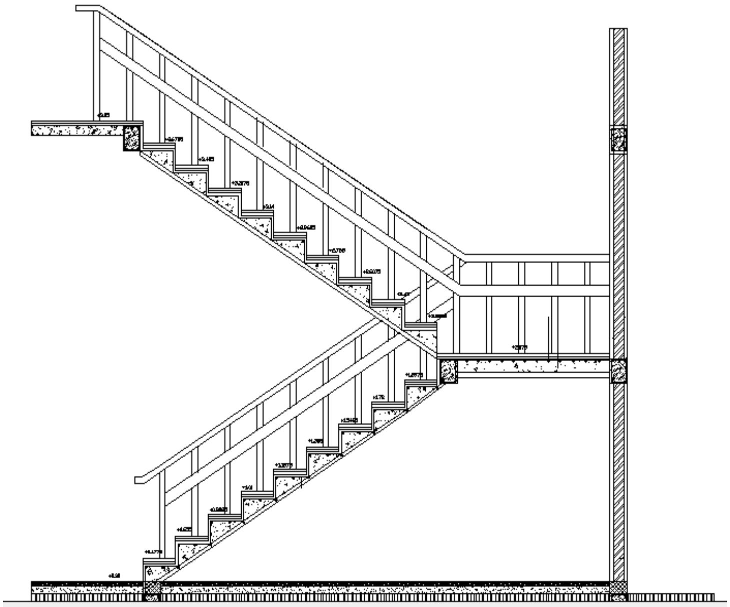


Figure 7. Stair side view

Analysis of Seismic Evaluation

Static Linear Analysis

Static linear analysis is conducted using equivalent static load analysis. The analysis is conducted on Non-Masonry Model. The base shear (V) occurring at the structural basic level is calculated using an equation based on SNI 03-1726-2002 and SNI 1726:2012. The base shear (V) is then distributed to the whole building structures to become the nominal equivalent static seismic load (F_i) through joints on each floor. The base shear (V) and equivalent static seismic load (F_i) based on SNI 03-1726-2002 are shown in Equation 1 and Equation 2, respectively, while based on SNI 1726:2012 are shown in Equation 3 and Equation 4, respectively.

$$V=\frac{C_1 I}{R} Wt \quad (1)$$

$$F_i=\frac{W_i Z_i}{\sum_{i=1}^{n} W_i Z_i} V \quad (2)$$

$$V=C_s \times W \quad (3)$$

$$C_S=\frac{S_{DS}}{\frac{R}{I_e}} \quad (4)$$

Dynamic Response Analysis

The spectrum dynamic response seismic loads based on SNI 03-1726-2002 and SNI 1726:2012 are used in dynamic response analysis by adjusting site clasiffication and seismicity level in Purbalingga regency. Dynamic response analysis uses damping of 0.05. The dynamic response analysis is conducted using a 3-dimensional model. In order that spectrum response is possibly modeled using SAP 2000 software (Computer and Structures, Inc., 2016), the function of the response spectrum is defined in a dialog box of Spectrum Response Function Definition. The definition is conducted by inputting data of the fundamental period of structure (T) and those of spectral response accelerations (Sa). To simulate the planned earthquake arbitrary load toward building structure model, the seismic loading influence on major effective directions of 100% is considered occurring at the same time with seismic loading influence at a perpendicular direction to the main direction by only 30% of effectiveness. Baesd on SNI 03-1726-2002, response spectrum shall be developed as follow:

$$A_m=2,5A_0 \qquad (5)$$

for $T < T_c$:

$$C=A_m \qquad (6)$$

for $T > T_c$:

$$C=\frac{A_r}{T} \qquad (7)$$

where

$$A_r=A_m T_c \qquad (8)$$

In addition, baesd on SNI 1726:2012, response spectrum shall be developed as follow:

For periods less than or equal to T0, Sa shall be taken as given by Equation 9.

$$S_a=S_{DS}\left(0,4+0,6\frac{T}{T_0}\right) \qquad (9)$$

For periods greater than or equal to T_0 and less than or equal to *TS*, *Sa* shall be taken as equal to S_{DS}.
For periods greater than T_S and less then or equal to T_L, *Sa* shall be taken as given by Equation 10.

$$S_a=\frac{S_{D1}}{T} \qquad (10)$$

Pushover Analysis

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern (Habibullah and Pyle, 1998; Pranata, 2006). With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behavior and load reversals being estimated by using modified monotonic force-deformation criteria and with damping approximations. The following steps (Habibullah and Pyle, 1998) are included in the pushover analysis. Steps 1 through 4 discuss creating the computer model, step 5 runs the analysis, and steps 6 through 10 reviews the pushover analysis results.

1. Create the basic computer model (without the pushover data) using SAP2000 (Computer and Structures, Inc., 2016).
2. Define properties and acceptance criteria for the pushover hinges. The program includes several built-in default hinge properties that are based on average values from ATC-40 (ATC, 1996) for concrete members and average values from FEMA 273 (FEMA, 1997) for steel members. These built in properties can be useful for preliminary analyses, but userdefined properties are recommended for final analysis.
3. Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and hinge locations.
4. Define the pushover load cases. In SAP2000 (Computer and Structures, Inc., 2016) more than one pushover load case can be run in the same analysis. Also a pushover load case can start from the final conditions of another pushover load case that was previously run in the same analysis. Typically the first pushover load case is used to apply gravity load and then subsequent lateral pushover load cases are specified to start from the final conditions of the gravity pushover. Pushover load cases can be force controlled, that is, pushed to a certain defined force level, or they can be displacement controlled, that is, pushed to a specified displacement. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled. SAP2000 (Computer and Structures, Inc., 2016) allows the distribution of lateral force used in the pushover to be based on a uniform acceleration in a specified direction, a specified mode shape, or a user-defined static load case.
5. Run the basic static analysis and, if desired, dynamic analysis. Then run the static nonlinear pushover analysis.
6. Display the pushover curve. The file menu allows us to view and if desired, print to either a printer or an ASCII file, a table which gives the coordinates of each step of the pushover curve and summarizes the number of hinges in each state.
7. Display the capacity spectrum curve. Note that we can interactively modify the magnitude of the earthquake and the damping information on this form and immediately see the new capacity spectrum plot. The performance point for a given set of values is defined by the intersection of the capacity curve

and the single demand spectrum curve. Also, the file menu in this display allows us to print the coordinates of the capacity curve and the demand curve as well as other information used to convert the pushover curve to Acceleration-Displacement Response Spectrum format (also known as ADRS format).

8. Review the pushover displaced shape and sequence of hinge formation on a step-by-step basis. Hinges appear when they yield.
9. Review member forces on a step by step basis.
10. Output for the pushover analysis can be printed in a tabular form for the entire model or for selected elements of the model. The types of output available in this form include joint displacements at each step of the pushover, frame member forces at each step of the pushover, and hinge force, displacement and state at each step of the pushover.

Results and Discussions

Results of Linear Static Analysis

The base shear (V) on the moderate soil type occurring in the structure's basic level calculated based on SNI 03-1726-2002 is 4929.53 kN for X direction and 6433.04 kN for the Y direction. While the base shear referring to SNI 1726: 2012 is 3426.77 kN for X direction and 4471.94 kN for the Y direction. The base shear is reduced by 30.48%. The drift ratio experiences an average decrease of 34.42% and 32.61% respectively for X and Y direction as shown in Figure 8.

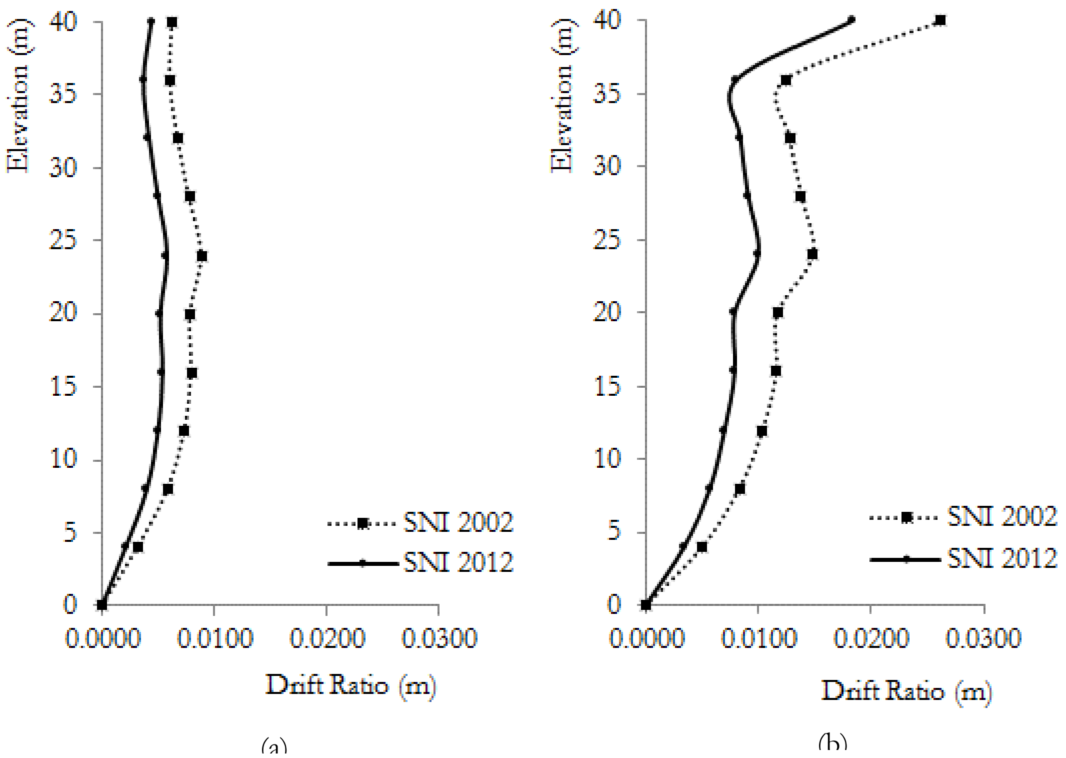


Figure 8. Drift ratio resulted from the liner static analysis, (a) X direction, (b) X direction

Results of Dynamic Response Analysis

In Purbalingga, the response spectrum referring to SNI 03-1726-2002 is greater than that to SNI 1726:2012 as shown in Figure 9. Thus, if the apartment building model made earlier before referring to SNI 03-1726-2002, it is obvious that it also meets the requirements of SNI 1726:2012. The results of dynamic response analysis show that the drift ratio decreases at the average level of 30.74% and 27.33% respectively for X and Y direction as shown in Figure 10.

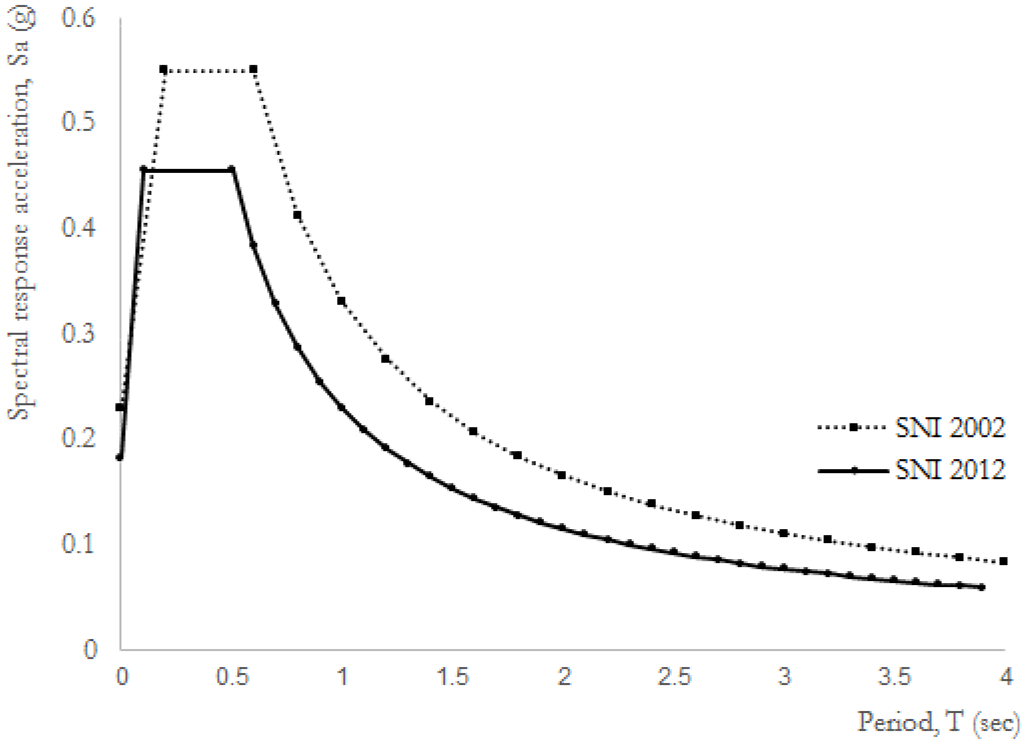
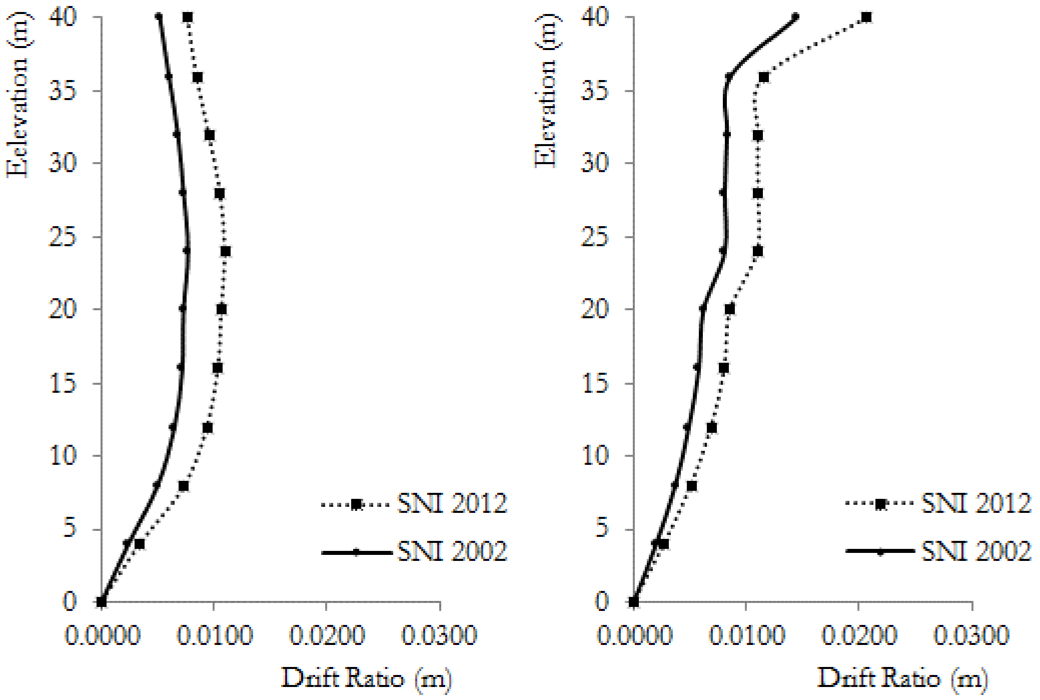


Figure 9. The response spectrum for moderate soils in Purbalingga



(a)

(b)

Figure 10. Drift ratio resulted from the dynamic response analysis, (a) X direction, (b) Y direction

Results of Pushover Analysis

The results of pushover analysis show that the value of basic shear (V) and displacement (D) occurs when the apartment building model nearly collapses. The Value of Sa, Sd, effective natural period (T_{eff}) and effective viscous damping (β_{eff}) may also be figured out. The results are based on SNI 03-1726-2002 and SNI 1726:2012 presented in Table 1 shows that the base shea decreases by 30.57% for X direction and by 18.27% for Y direction due to the apartment building models in Purbalingga regency when the performance point is already reached. Ductility structure is obtained by comparing the ultimate displacement value (δ_u) and the yield displacement (δ_y) as presented in Table 2

Table 1. Comparison of pushover analytical results

Parameter	**SNI**			
	2002		**2012**	
	Direction X	**Direction Y**	**Direction X**	**Direction Y**
V (kg)	7571.40	7420.61	5256.80	6064.94
D (m)	0.077	0.061	0.053	0.050
S_a	0.545	0.550	0.379	0.045
S_d	0.050	0.036	0.035	0.290
T_{eff}	0.607	0.511	0.067	0.511
β_{eff}	0.05	0.05	0.05	0.05

Table 2. Ductility of structure

Direction	δ_y **(m)**	δ_u **(m)**	**Ductility**
X	0.21229	0.21714	1.02
Y	0.19704	0.64398	3.27

The apartment building model structural performance is determined by story drift, that is, control point's drift ratio (roof) with its height. The pushover analysis results show that the occurring story drift is 0.193% at X direction and 0.153% at Y direction for the seismic load of SNI 03-1726-2002 while for the seismic load of SNI 1726:2012, the story drift is 0.133% at direction X and is 0.125% at Y direction. The drift levels of pushover analytical results are shown in Figure 11, while the structural performance is presented in Table 3.

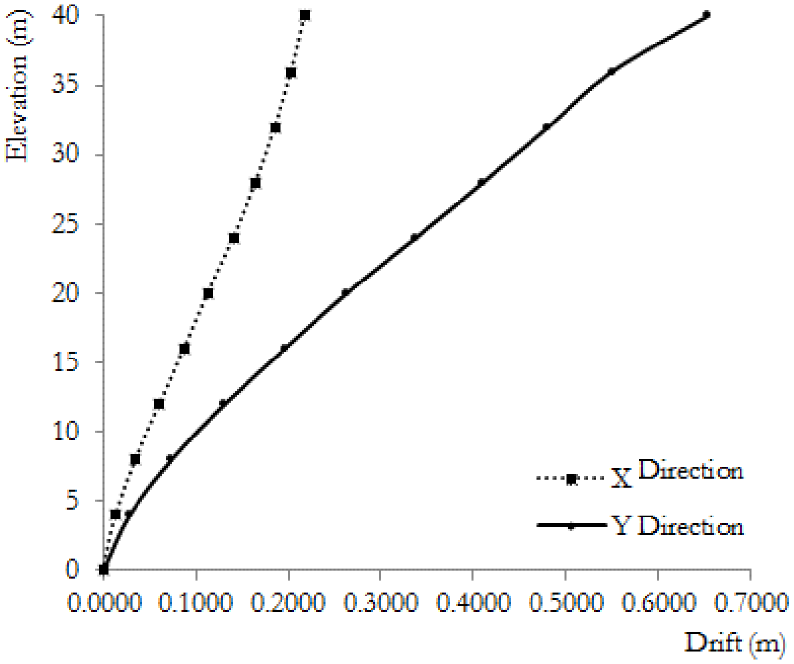


Figure 11. Drifts of X and Y direction resulted from the pushover analysis

Table 3. Structural performance

SNI	**Direction**	**Dt (m)**	**Elevation (m)**	**Story Drift (%)**	**Performance**
2002	**X**	0.0770	40	0.193	*IO*
	Y	0.0610	40	0.153	*IO*
2012	**X**	0.0530	40	0.133	*IO*
	Y	0.0500	40	0.125	*IO*

The drift of apartment building model in Purbalingga regency analyzed at Y direction is greater than that at X direction because there is difference stiffness in which X direction is stiffer than Y direction. There are several causing factors including strong axis column mounting at the same direction leading to the X axis, the shear wall position is at the same direction leading to the X axis, and the stair structure at the same position leading to the X axis. The value of story drift is less than 1% that the performance of apartment building model in Purbalingga regency does not experience changes, remaining at the level of Immediate Occupancy (IO).

Conclusion

Based on linear static analysis, it shows that there is a base shear decrease (V) of 30.48%. The results of the static linear analysis also show that the drift ratio experiences an average decrease of 34.42% and 32.61% respectively for X direction and Y direction. The drift ratio based on dynamic response analysis experiences an average decrease of 30.74% and 27.33% respectively for X direction and direction Y. The results of pushover analysis show that the performance of this apartment building model is still at Immediate Occupancy (IO) level as the post-earthquake damage state that remains safe to occupy, essentially retains the pre-earthquake design strength and stiffness of the structure. The risk of lifethreatening injury as a result of structural damage is very low, and although some minor structural repairs may be appropriate, these would generally not be required prior to reoccupancy. Plastic hinge distribution shows that the collapse initially starts at the beam elements. The plastic hinge distribution shows that the collapse initially starts at the beam elements.

Acknowledgement

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